Considering of mass production characteristics and requirements in the structural optimization process

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Challenges of the integration of the manufacturing simulation

Generation of procedures for virtual development of materials and components considering high loads:

- Because of the manufacturing process, the material is often inhomogeneous.
- In standard development processes the local deviations are not taken into account.

Possibility 1: Integration of the consideration of uncertainties in the design loop

Possibility 2: Integration of manufacturing process simulations in the design loop

→ Understanding reasons of the different material behaviors in different component domains.

[Schumacher 2018a]

Industrial Requirements based on Boris Künkler (automotive CAE Grand Challenge 2019 in Hanau, Germany)

	Stamping process	Cutting process	Casting, injection molding	Fiber mapping	Additive manu-facturing	Assembly process
Necessary information	pre-strains thinning …	laser and press cutting …	positions of pores …	orienta-tions of fibers …	pre-stress and manu. directions	sequence …
Engineer-ing rules	*example 1* smooth surface …	…	*example 2* No pores in high-loaded parts …	Fibers in load direction …	overhang-ing angle < 45° …	…
Process simulation	one-step-solver …	…	filling, solidifica-tion …	…	…	…

[Kuenkler 2019]

Content

- Automatic design loop
- Challenges of the integration of the manufacturing simulation
- Example 1: Integration of the stamping process simulation in the topology optimization loop of sheet metal parts
- Example 2: Integration of the casting process simulation in the shape optimization loop of casting parts
- Collection of further activities in the structural optimization community
- Conclusion
- References

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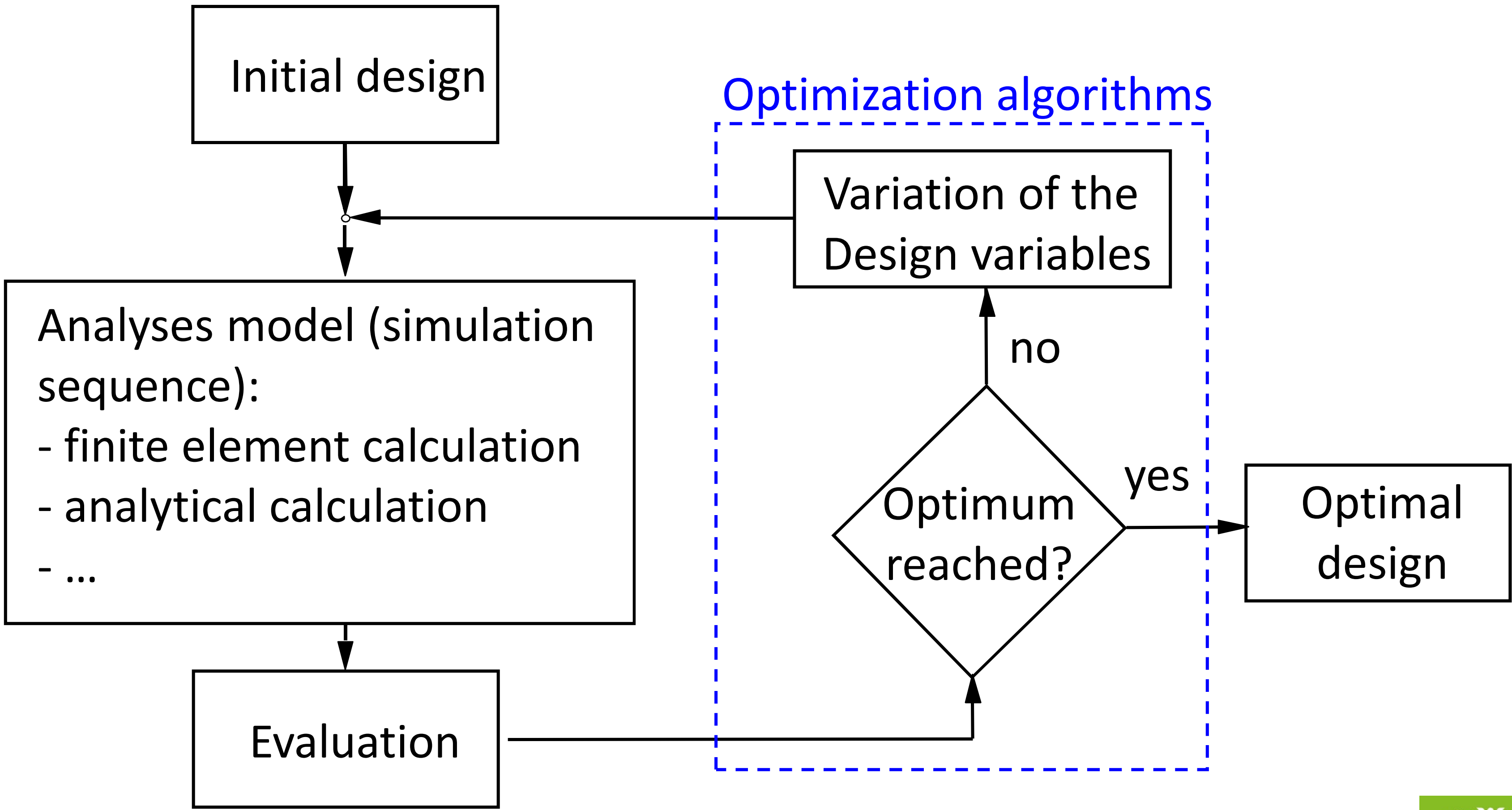
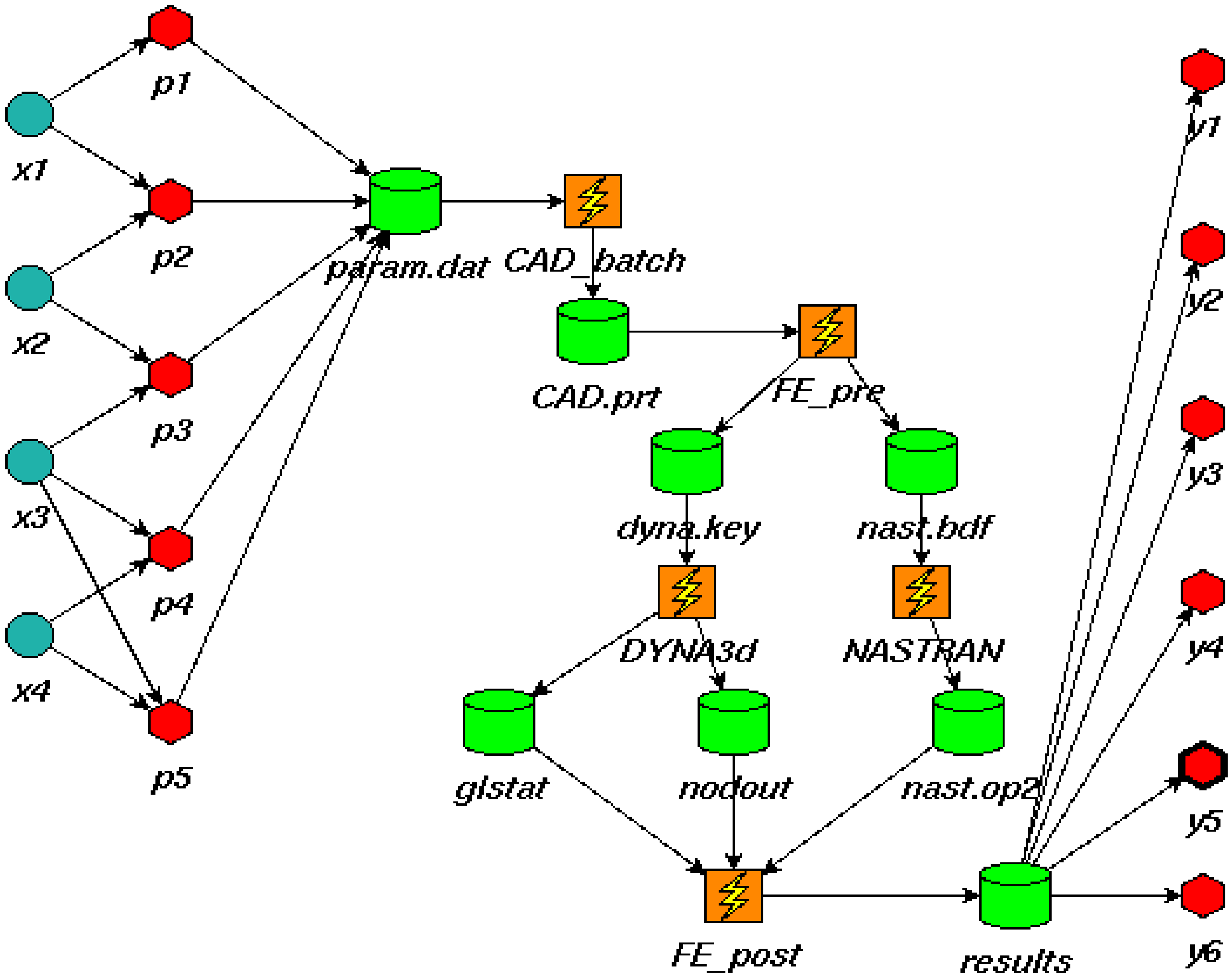
Automatic design loop: Using optimization algorithms



[Schumacher 2013]

Automatic design loop: Simulation sequence example



[Schumacher 2013]

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Challenges of the integration of the manufacturing simulation

Questions:

1. How is it possible to quantify the influence of the manufacturing process on the optimal design?
2. Are the simulation models of the manufacturing process good enough for using these in the design loop?
3. How to map the calculated local material behavior on the structural model?
4. Is it possible to use manufacturing simulations in an early stage of the design process?
5. What about the computer time for the simulation of the manufacturing process?

Example 1: Integration of the stamping process simulation in the topology optimization loop of sheet metal parts

SIMP Approach: Minimum compliance, 3D example

Optimization task:

- min. Compliance (= deformation energy)
- Volume fraction ≤ 6.25%

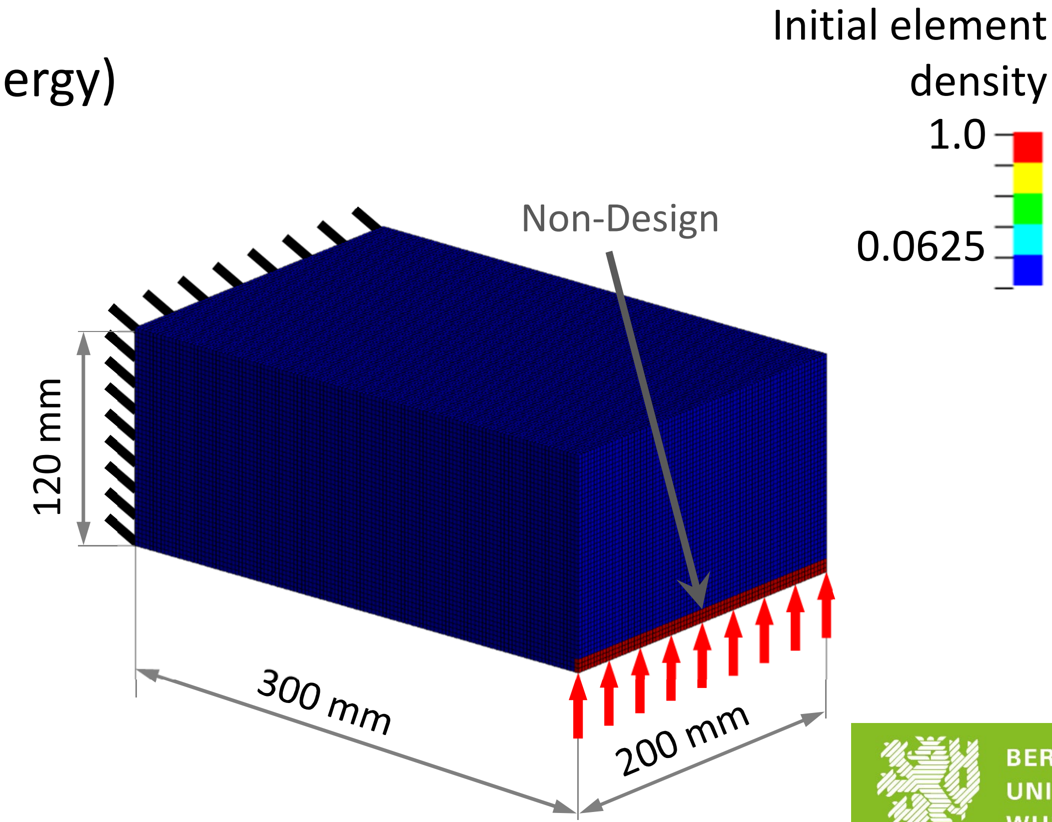
Structure and load case:

- Element edge length l_e = 2.5 mm
- Line load: 200 N/mm

Material: steel (E = 210 GPa, $v = 0.3$)

SIMP settings:

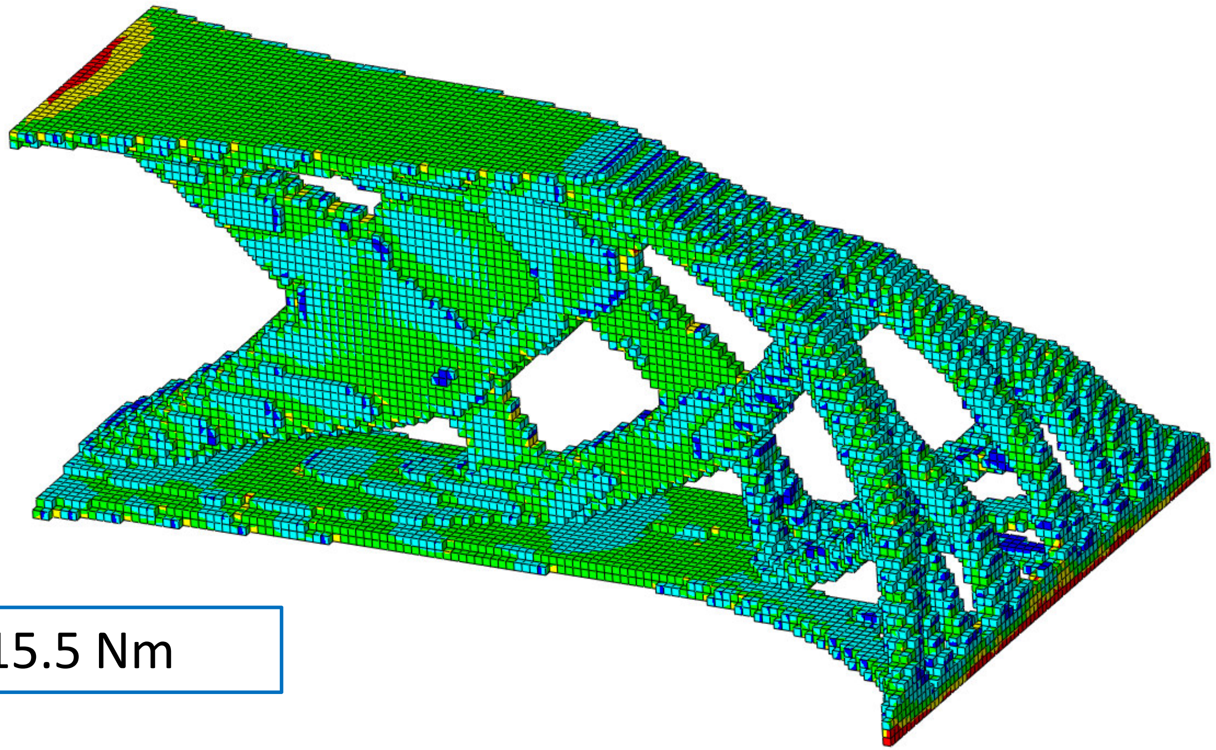
- Penalty exponent s = 3
- Filter radius r = 4.25 mm



[Dienemann 2017]

SIMP Approach: Minimum compliance, 3D example

Result without manufacturing constraints



Compliance: 15.5 Nm

[Dienemann 2017]

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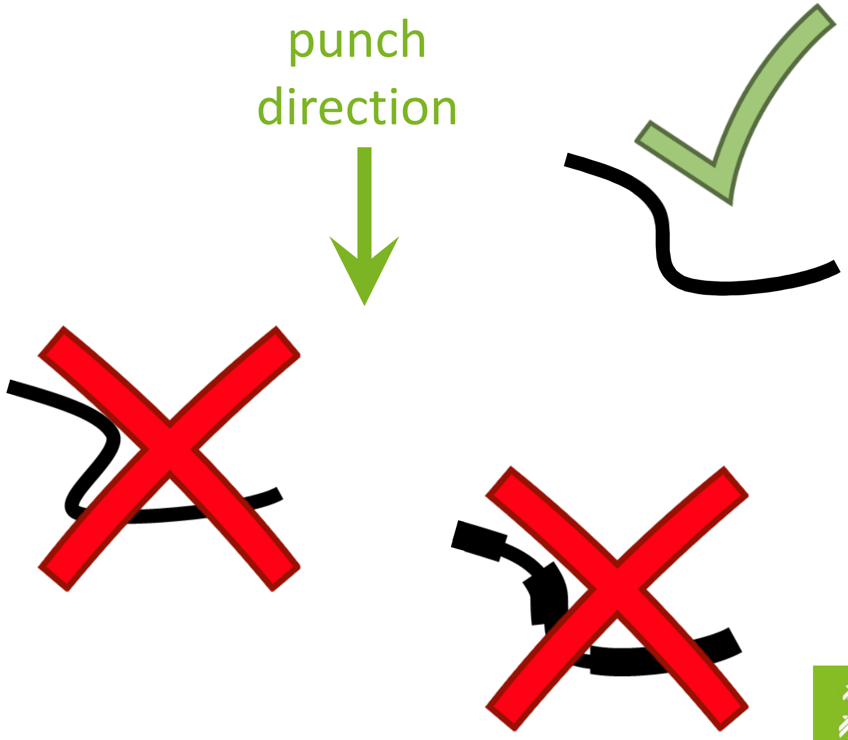
Considering of simple stamping requirements (1)

Advantages:

- Total freedom of mid surface design (no geometry parametrization) including beadings, no mesh distortion
- Optimized cut-outs

Challenges:

- Part manufactured by deep drawing
- No undercuts in punch direction
- Constant wall thickness
- …

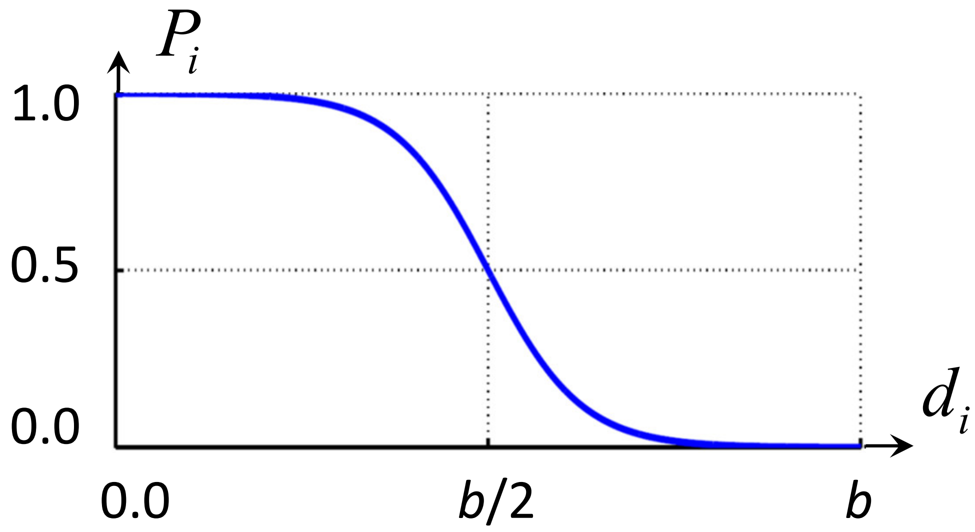


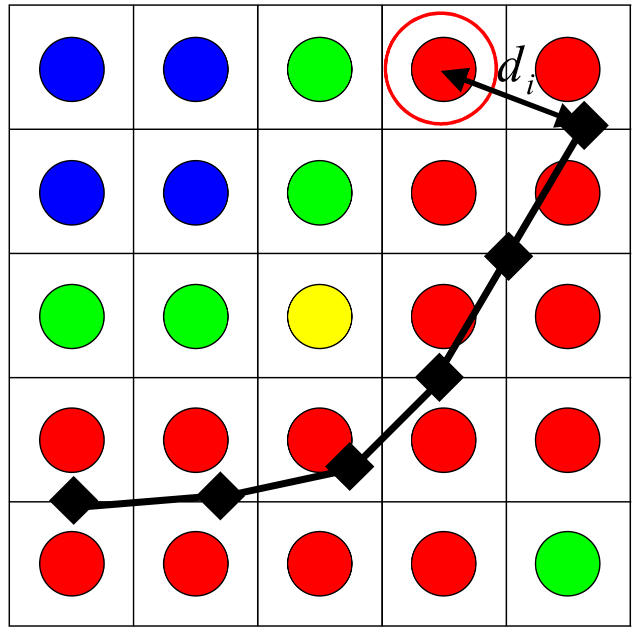
[Dienemann 2017]

Considering of simple stamping requirements (2)

Penalization of objective's sensitivities far away from mid surface

1. Calculation of mid surface
2. Penalization factor P_i (here: for negative sensitivities)





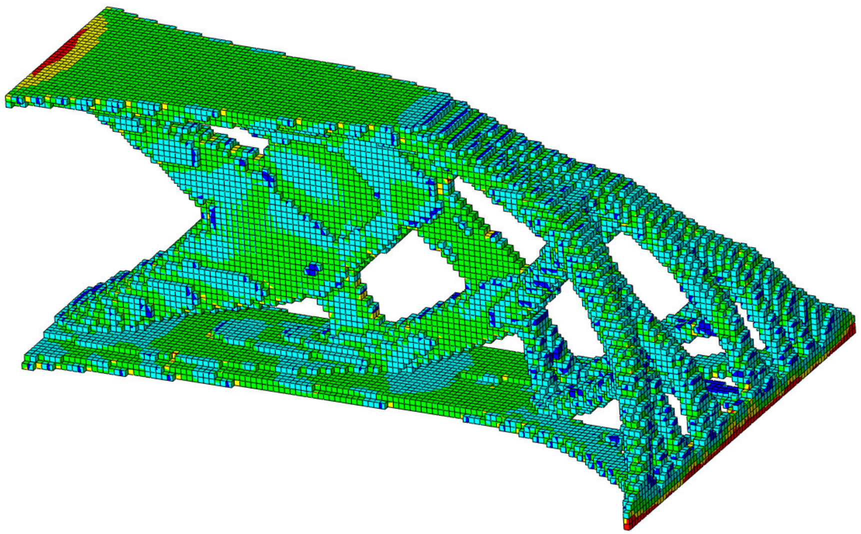
b – objective wall thickness

[Dienemann 2017]

Considering of simple stamping requirements (3)

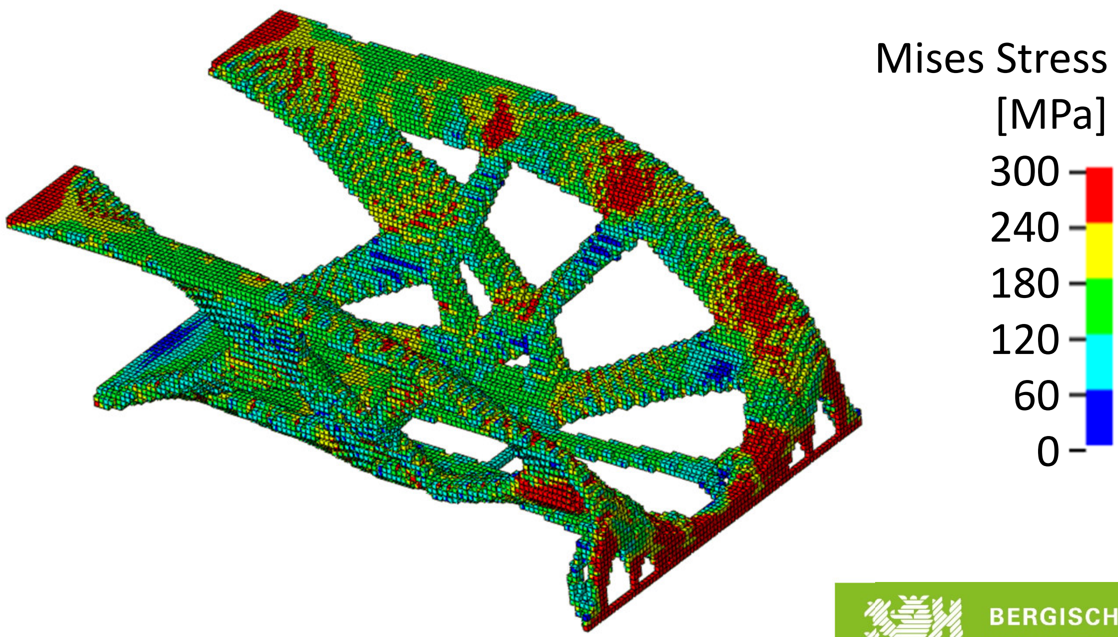
Design without stamping constraints:

Compliance: 15.5 Nm



Design with simple stamping constraints:

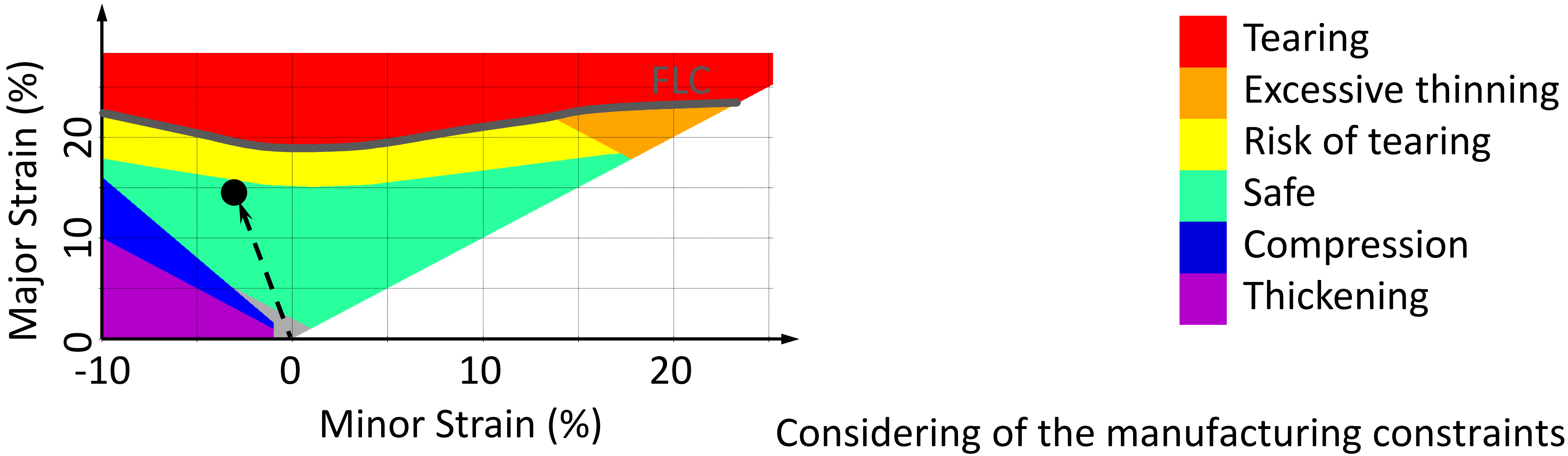
Compliance: 20.0 Nm



[Dienemann 2017]

Stamping process simulation: Forming Limit Diagram (1)

Integration of the stamping process simulation in the optimization loop:
Stamping process simulation of mid surface mesh with Autoform® OneStep



Considering of the manufacturing constraints with penalty function in the SIMP scheme:

→ Minimum corner radius

→ Avoid tearing

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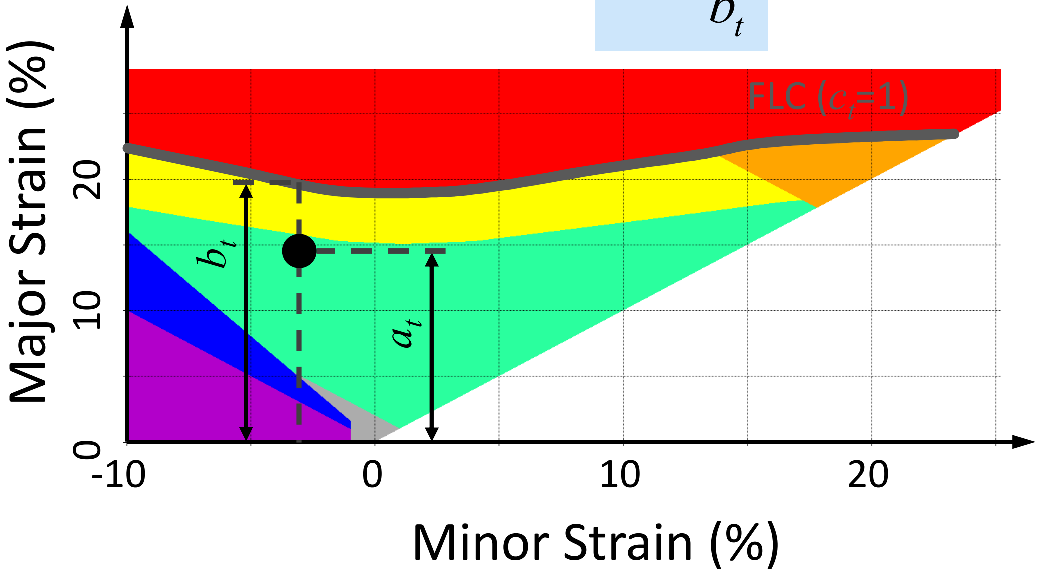
[Dienemann 2016]

Stamping process simulation: Forming Limit Diagram (2)

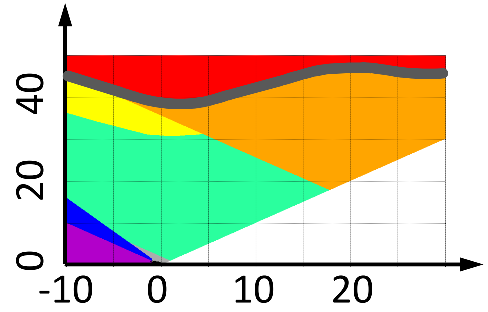
<u>Tearing criterion</u>

- Elemental result: tearing criterion
- Tearing at $c_t \geq 1$

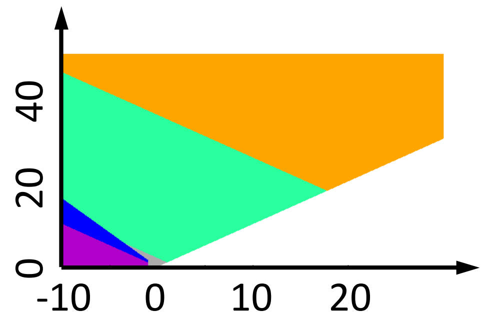
$$c_t = \frac{a_t}{b_t}$$



High-strength complex-phase steel, thickness 1 mm



Ductile cold forming steel, thickness 1 mm



Ductile cold forming steel, thickness 7.5 mm

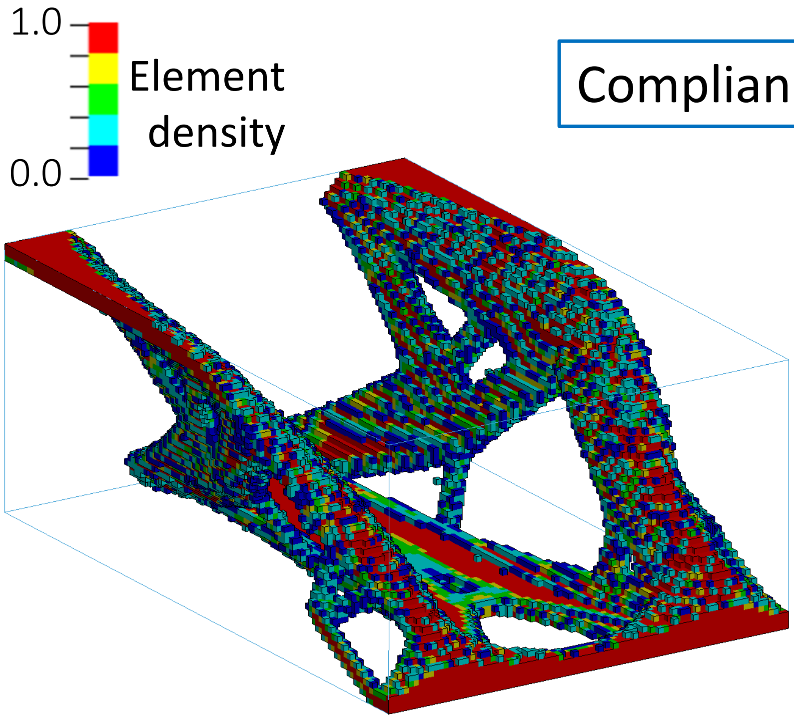
[Dienemann 2016]

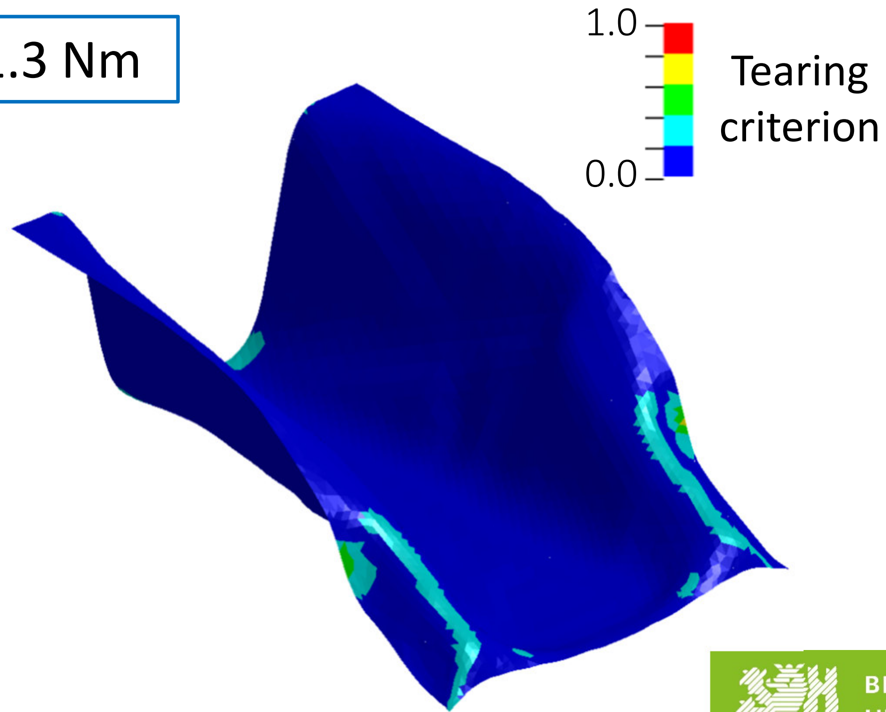
Topology optimization with an integrated stamping simulation

Integration of the stamping simulation with the following manufacturing sequence:

1. Deep drawing of initially flat sheet metal
2. Introducing cut-outs

Compliance: 21.3 Nm

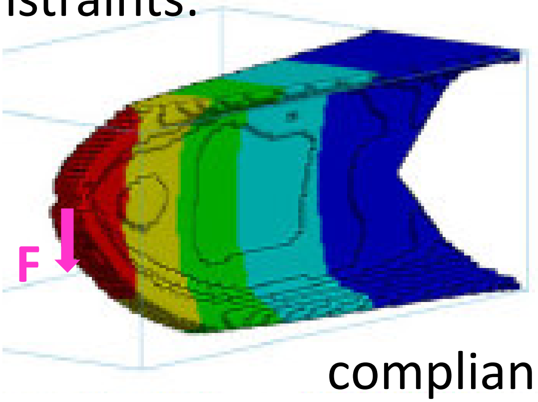


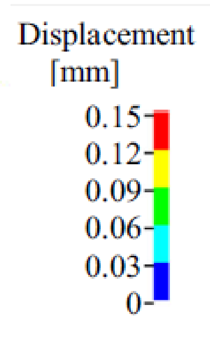


[Dienemann 2016]

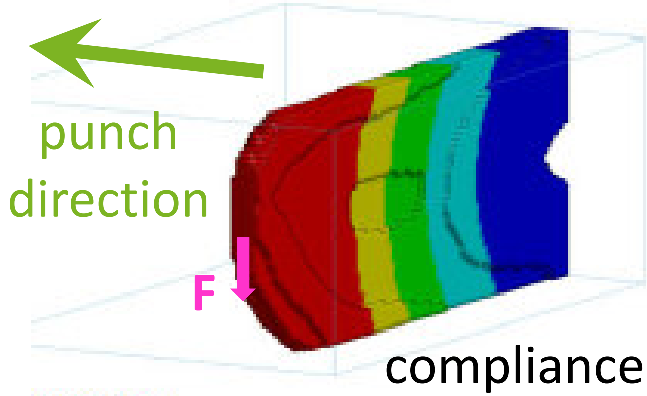
Topology optimization of shell structures
- Further study: Dependency on the punch direction

without manufacturing constraints:

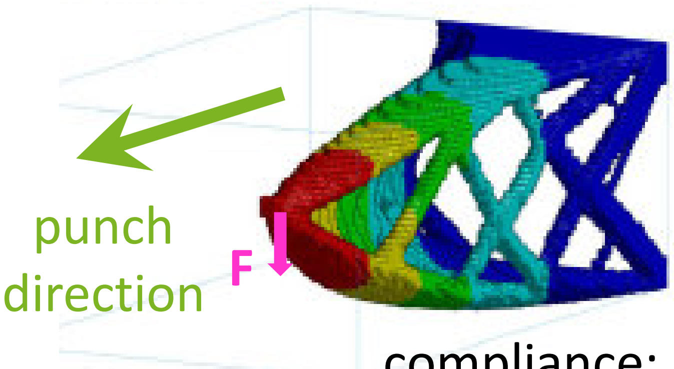




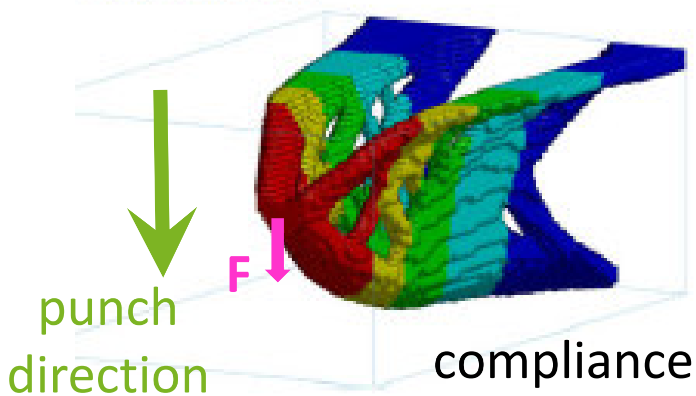
compliance: 100,0%



compliance: 140,0%



compliance: 122,0%

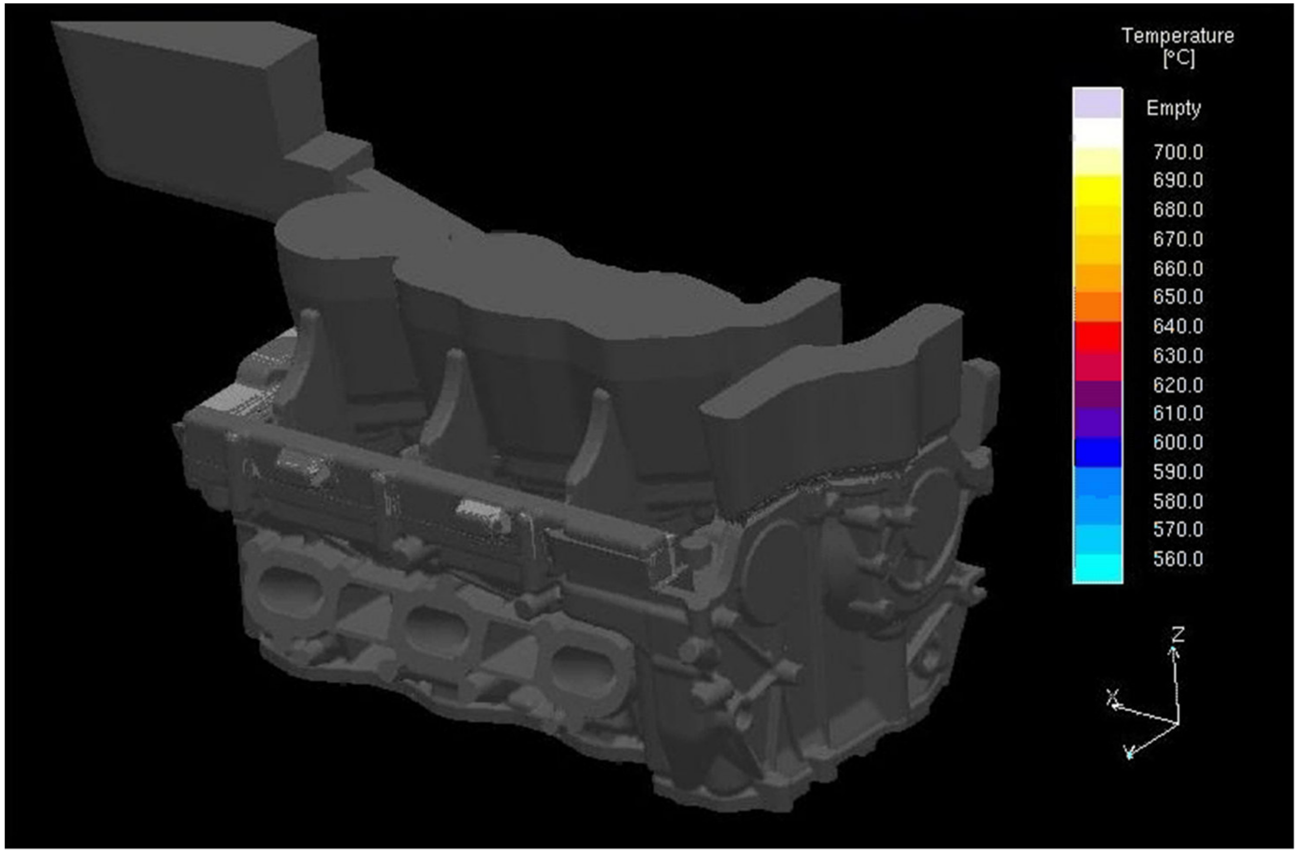


compliance: 122,5%

[Dienemann 2017]

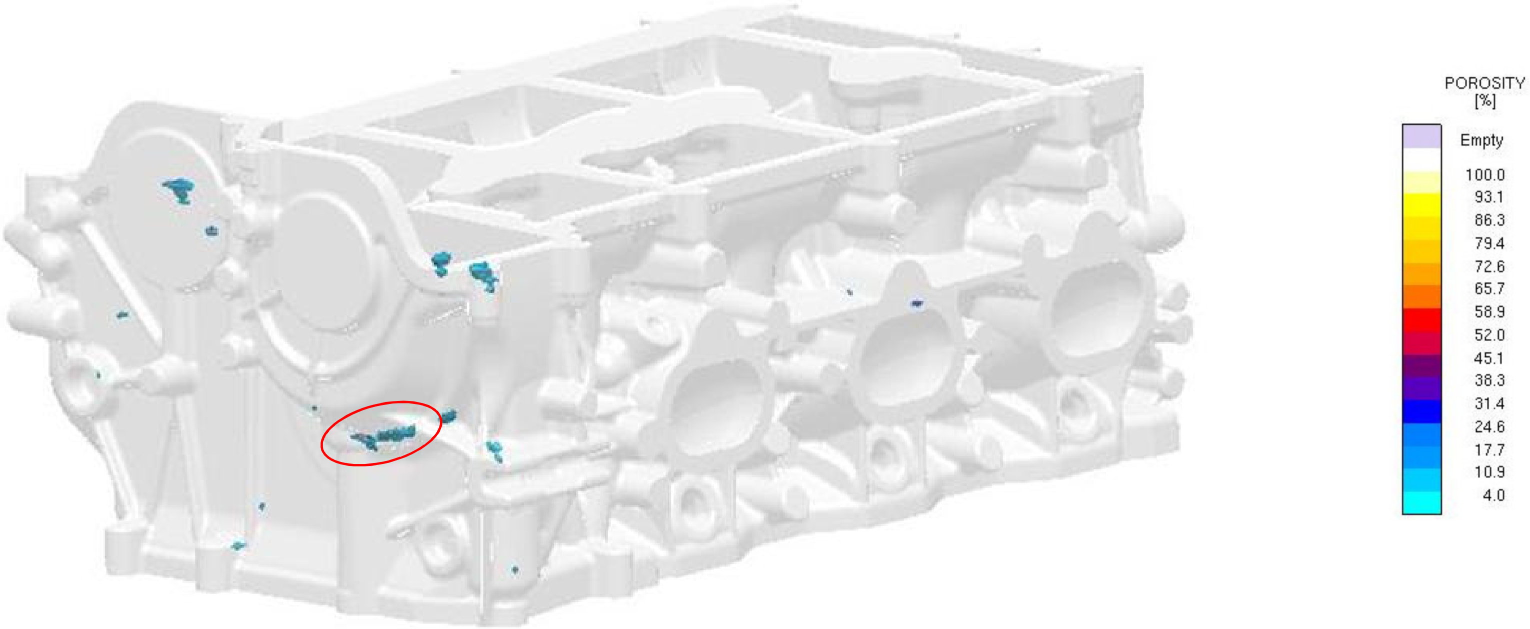
Example 2: Integration of the casting process simulation in the shape optimization loop of casting parts

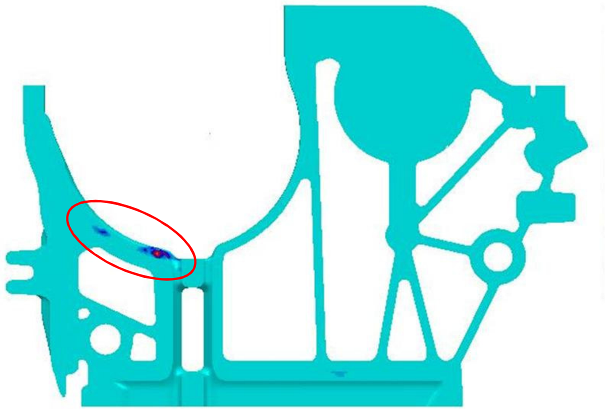
Filling and solidification of a cylinder head

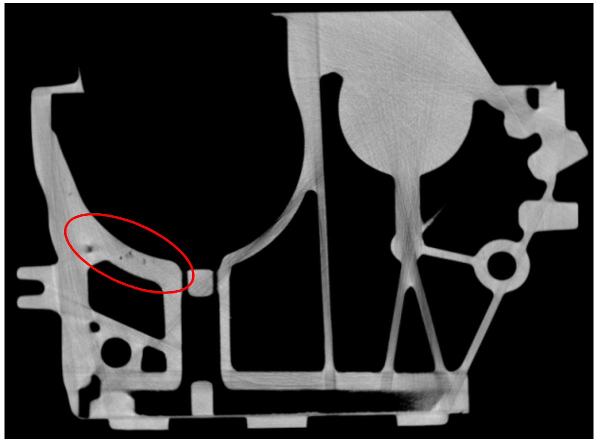


[Schumacher 2012]

Cylinder head: Calculated pores and hardware validation

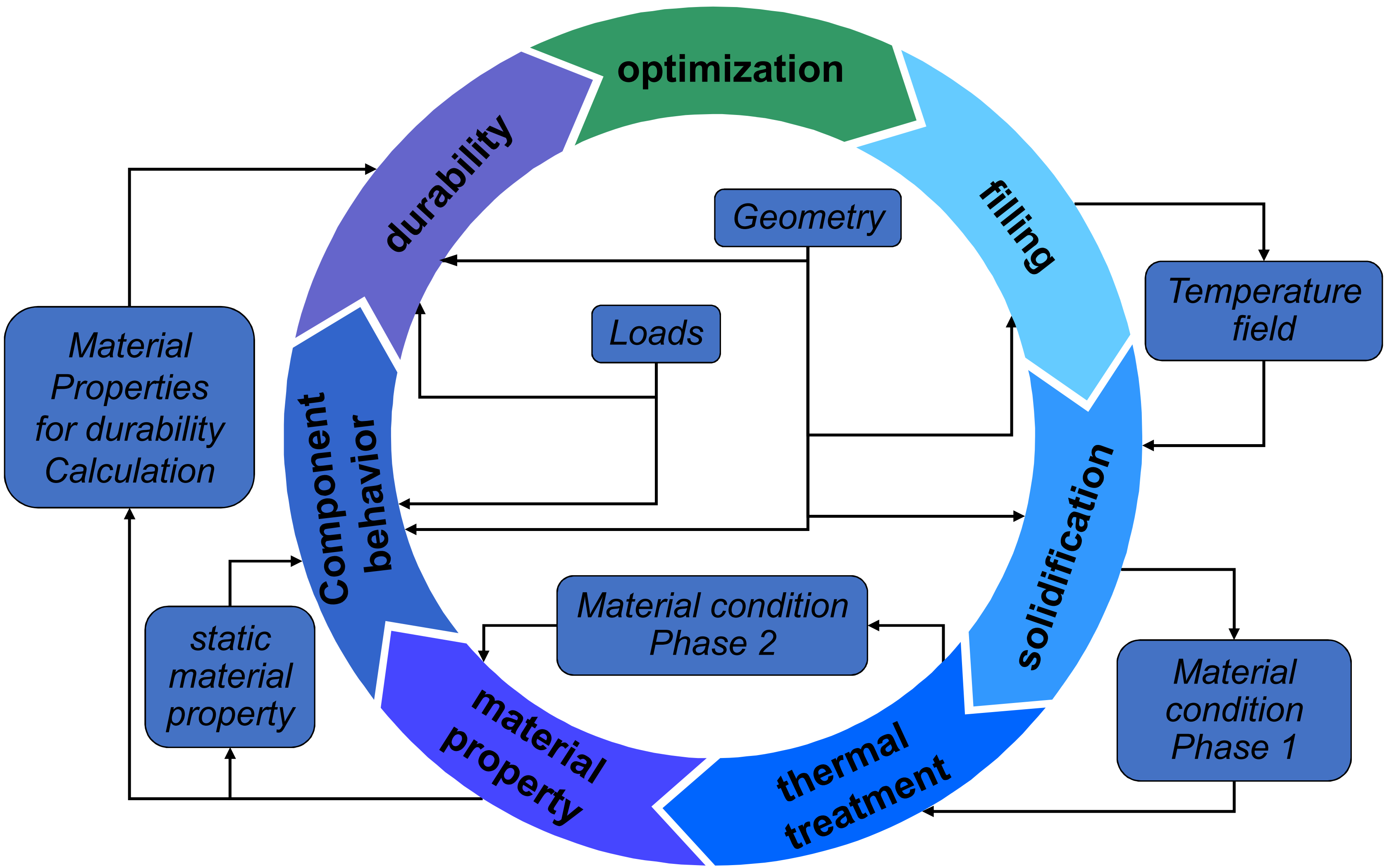






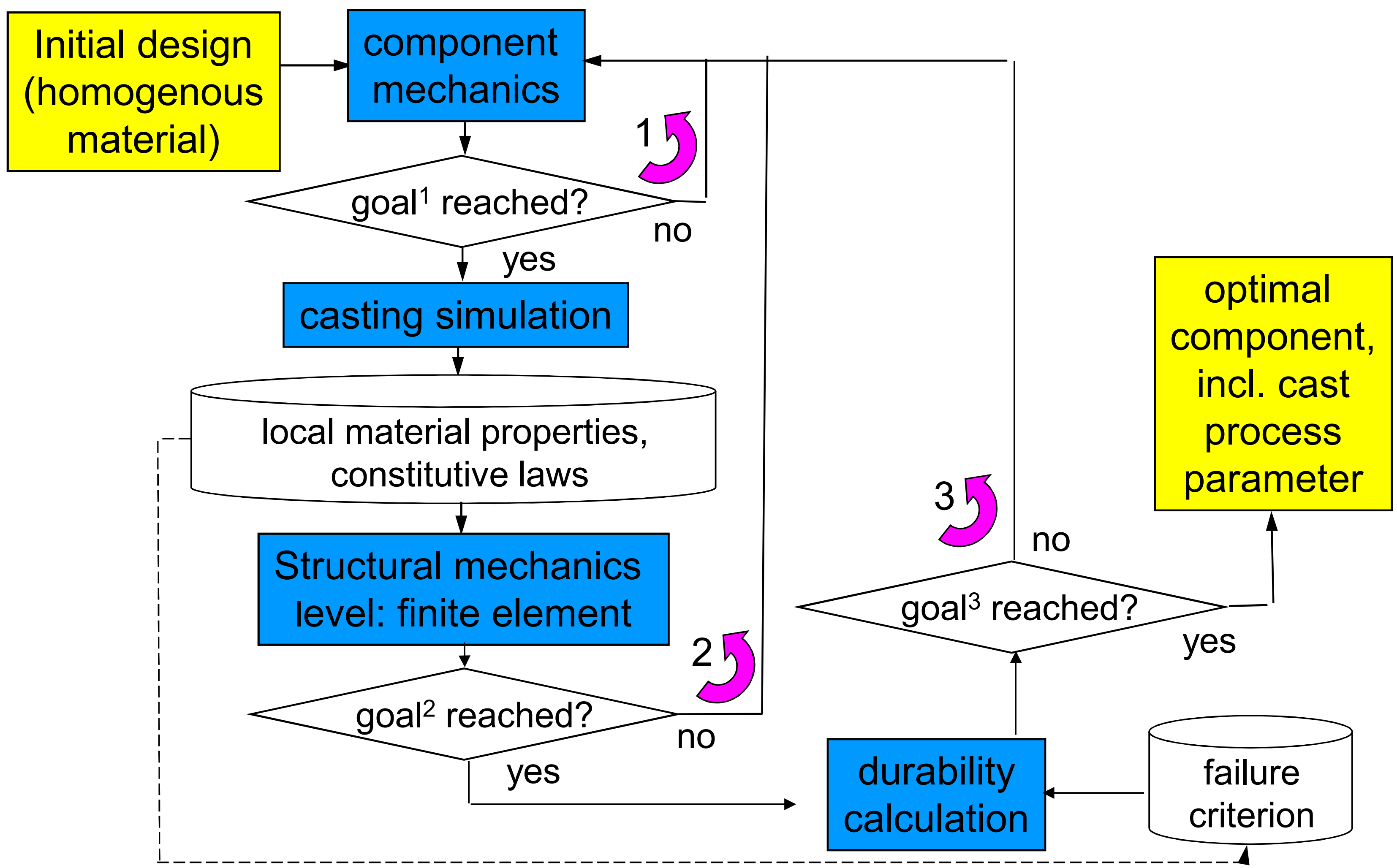
[Schumacher 2012]

OPTI-MAT: Main process



[Schumacher 2012]

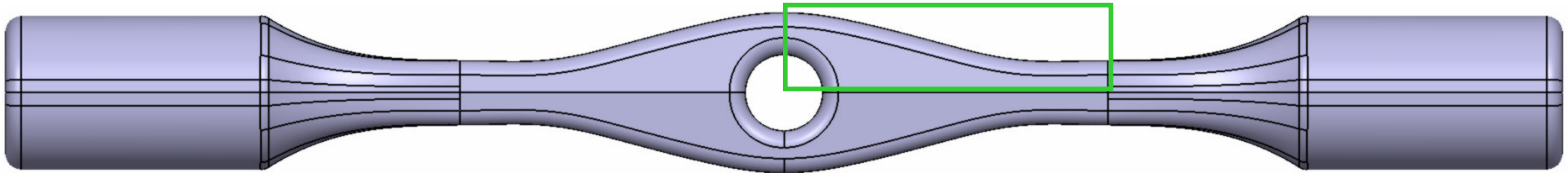
OPTI-MAT: Shape Optimization Scheme



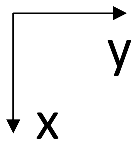
[Schumacher 2012]

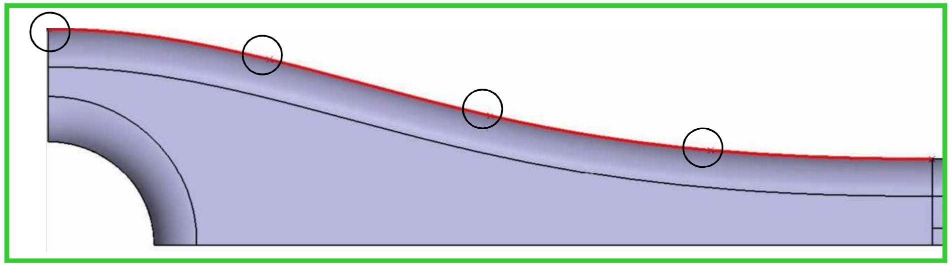
Component specimen example - description

- goal: reduction of maximum local stresses with a mass constraint
- design variables: four x-coordinates of the control points of a spline (tangential at the ends)
- non-linear material model for AlSi7MgCu0.5 and MAR-M-247
- constraints: Testing possibilities with standard tensile test equipment



length = 200 mm
radius head = 10 mm
radius hole = 5 mm
pull-off angle = 5°
corner radii = 2 mm





[Schumacher 2012]

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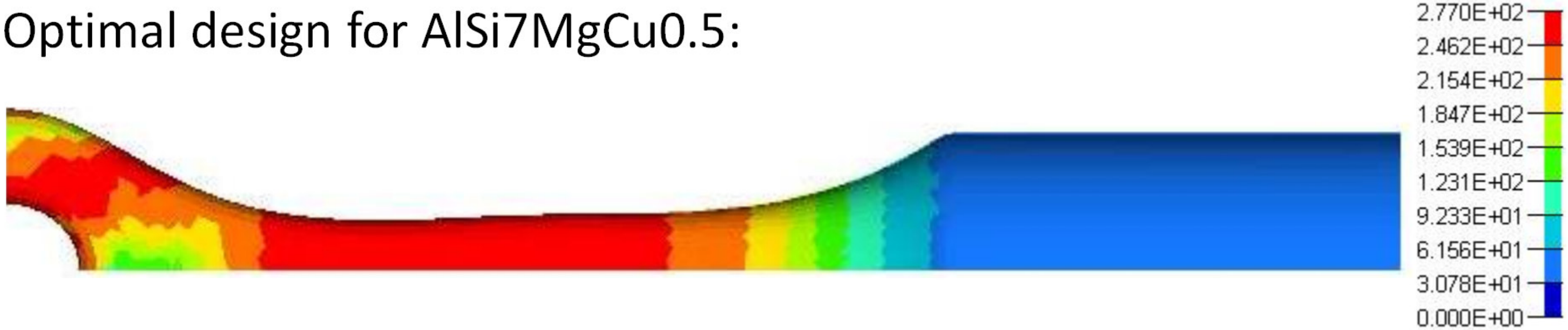
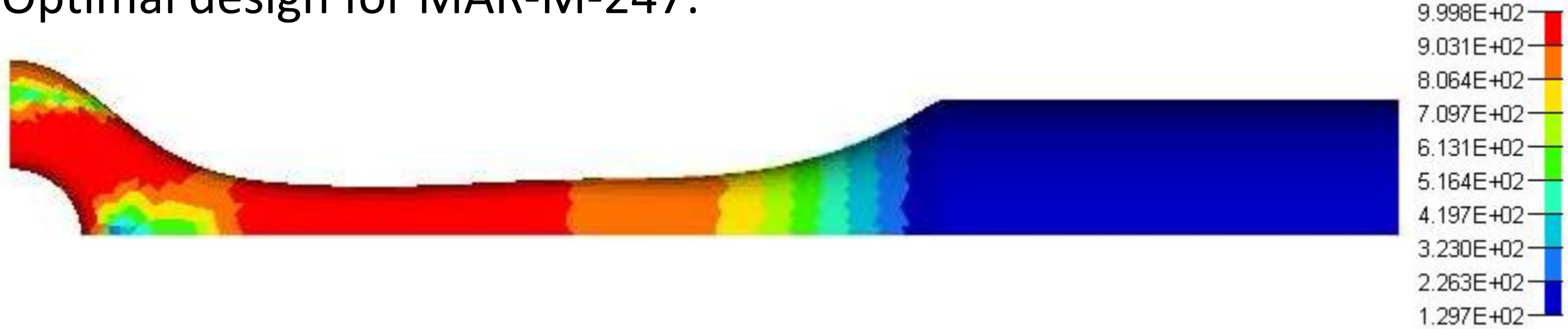
Component specimen example – optimization without an integration of a casting simulation

Optimal design for AlSi7MgCu0.5:



tensile test

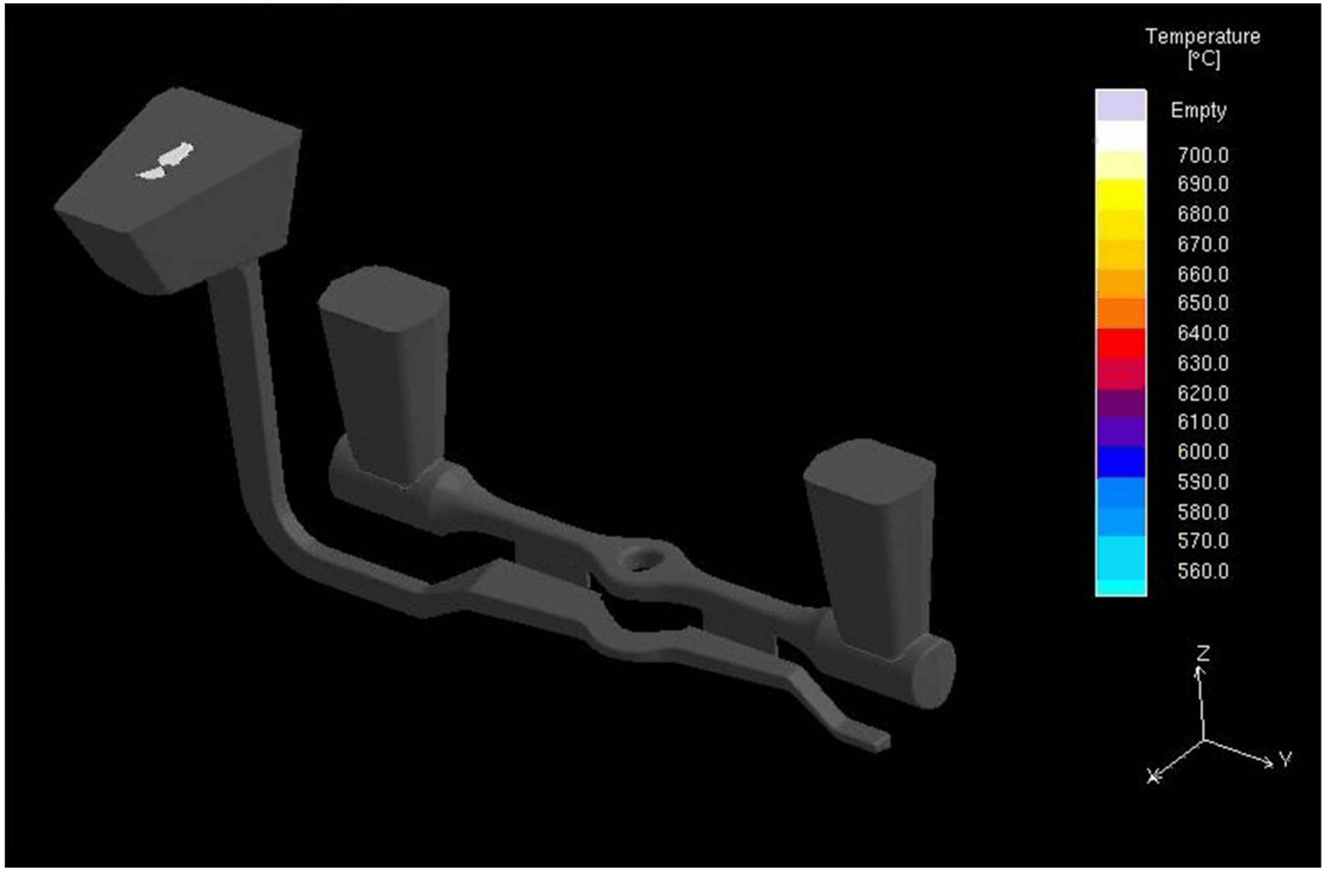
Optimal design for MAR-M-247:



[Schumacher 2012]

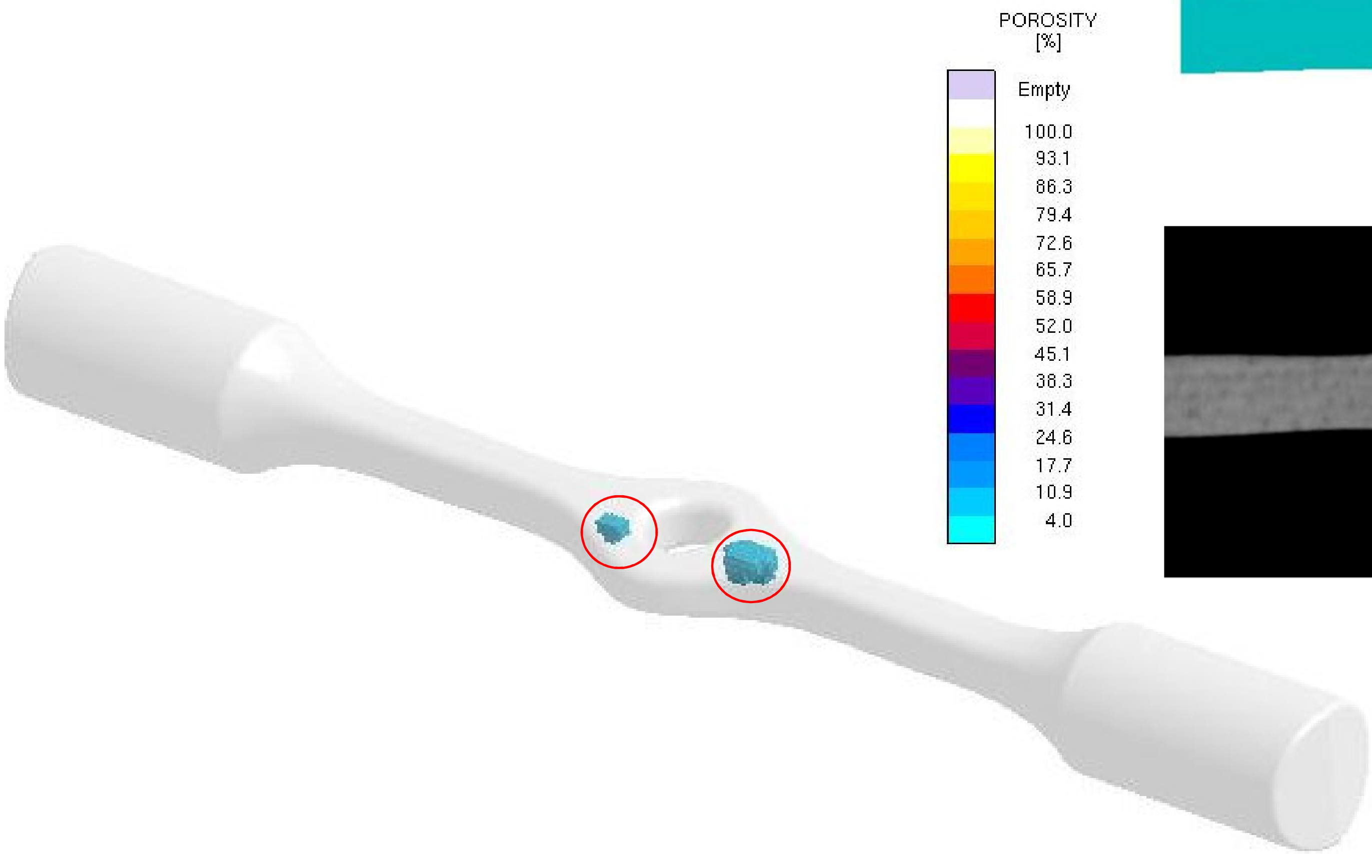
Component specimen example – casting simulation

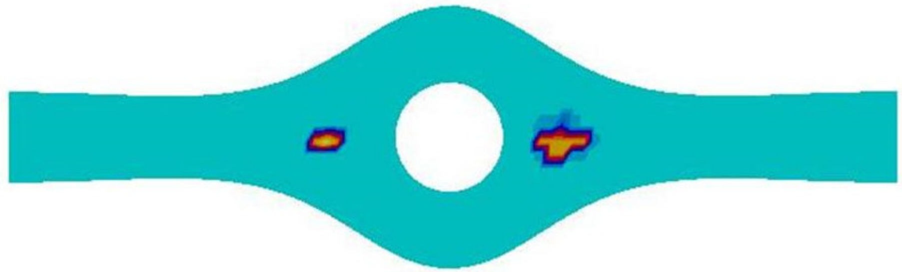
Filling and solidification

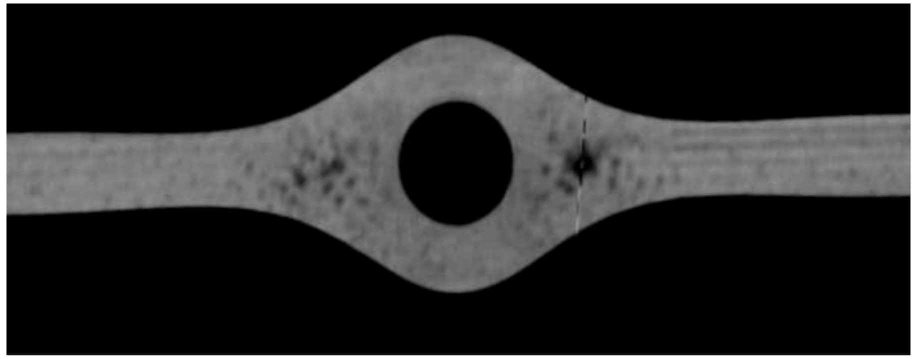


[Schumacher 2012]

Component specimen example – validation of the casting simulation



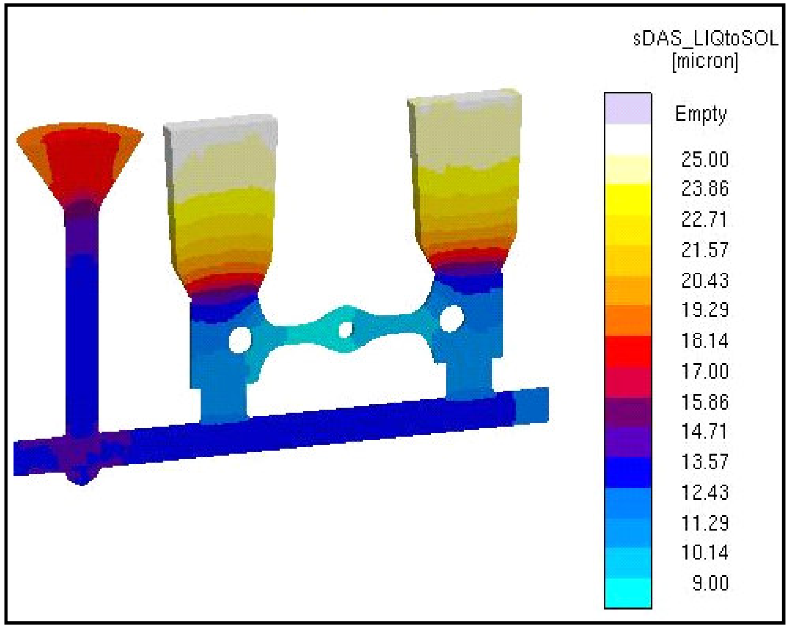


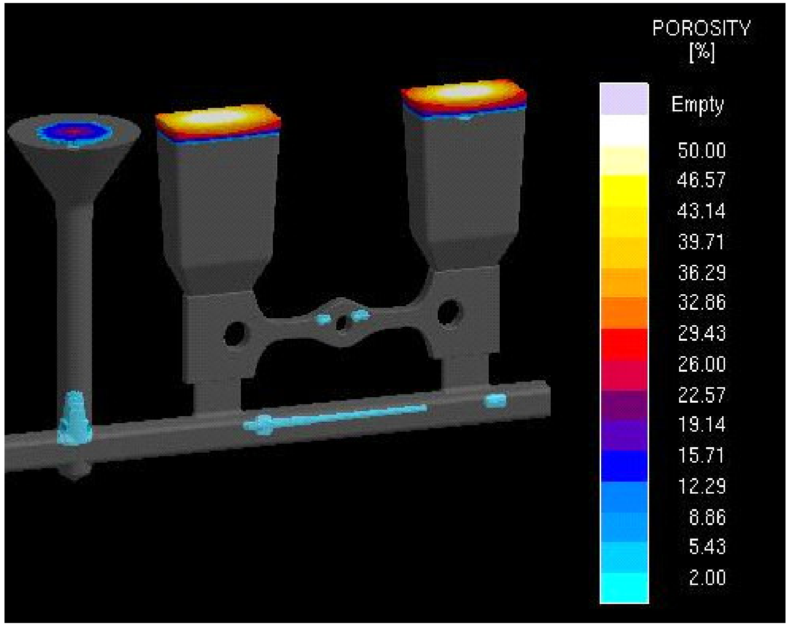


[Schumacher 2012]

Component specimen example – casting simulation results

The local mechanical behavior comes from the solidification conditions.





Young's Modulus distribution

porosity distribution

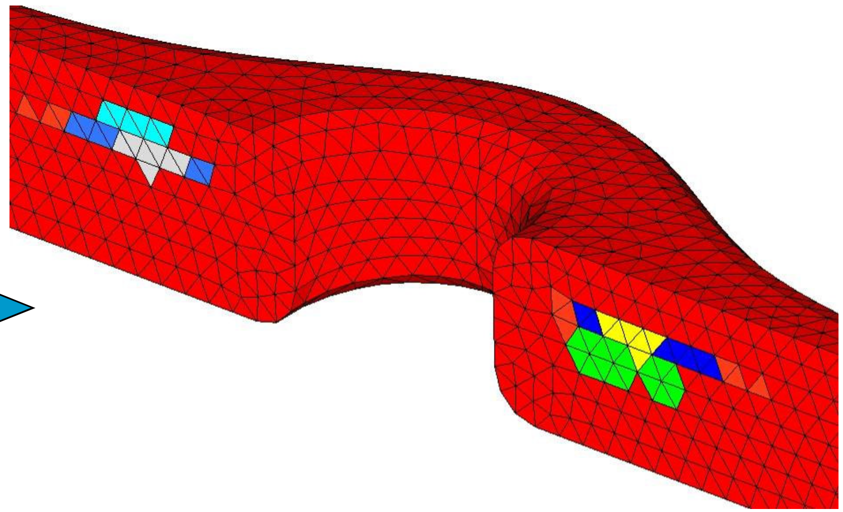
[Schumacher 2012]

Component specimen example – mapping of the pores

Simple approach:

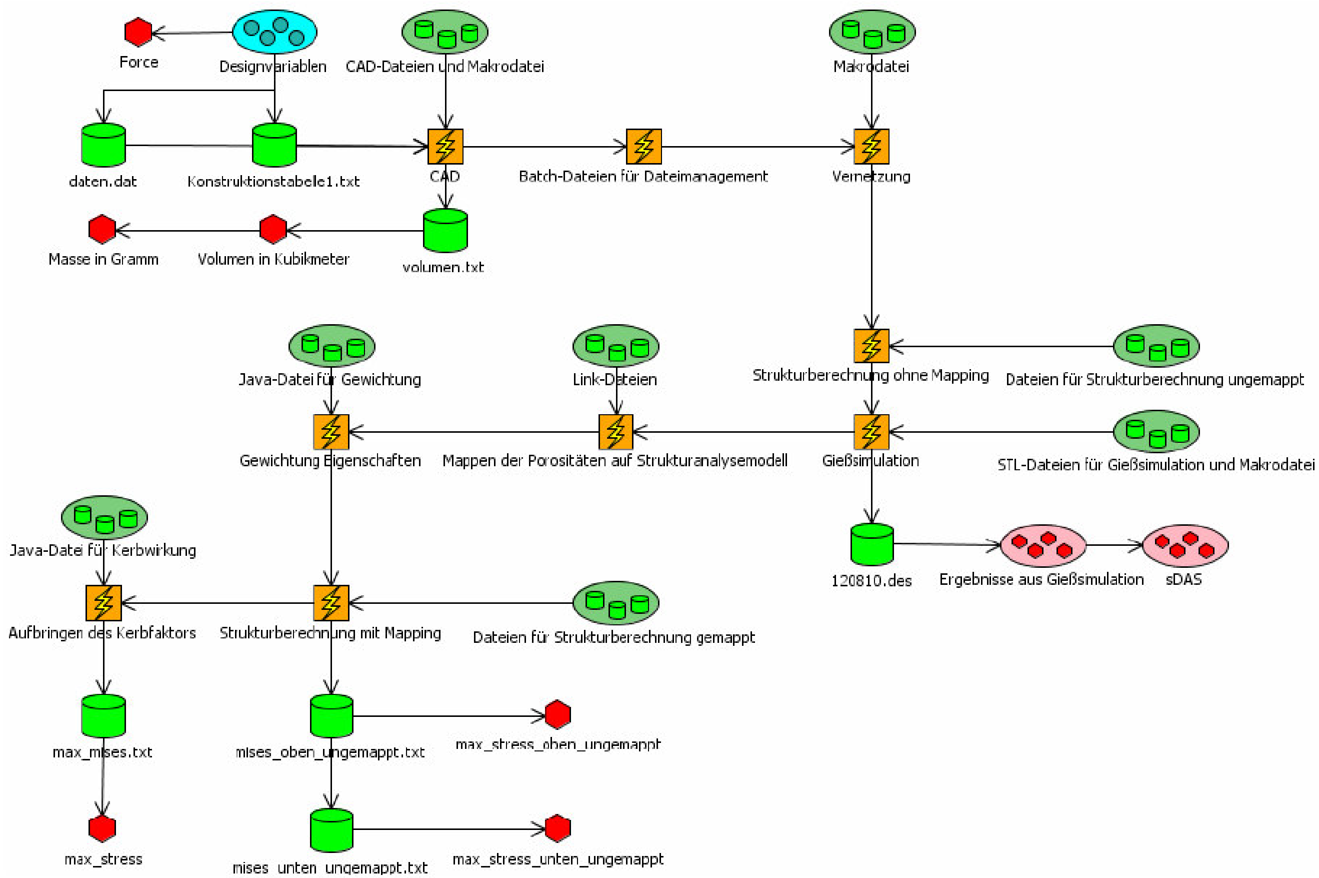
- Mapping the pore information from the casting simulation to the structural model
- Based on a porosity value the local material behavior of the finite elements of the structural model is changed.
- In addition to that, we calculate an increased stress concentration value using a notch factor of 2.1 (circular hole).

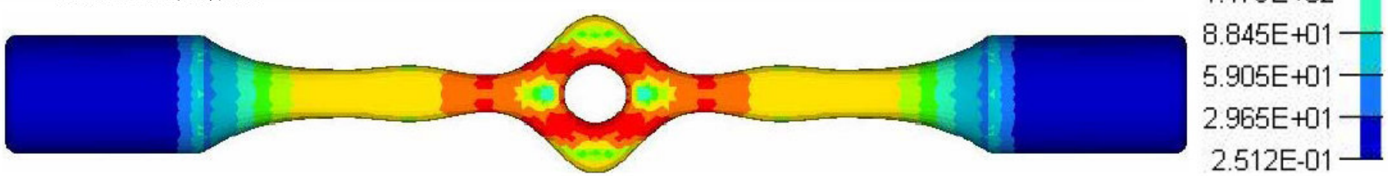
structural analysis model
with pore information



[Schumacher 2012]

Component specimen example – Optimal shape considering the coupled process





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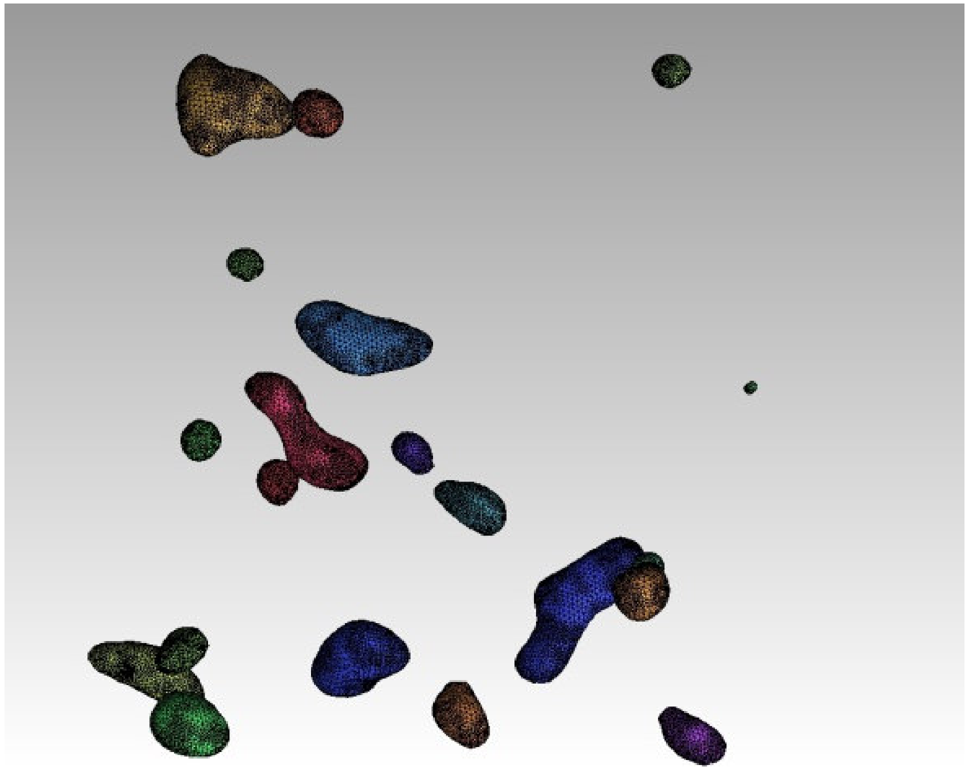
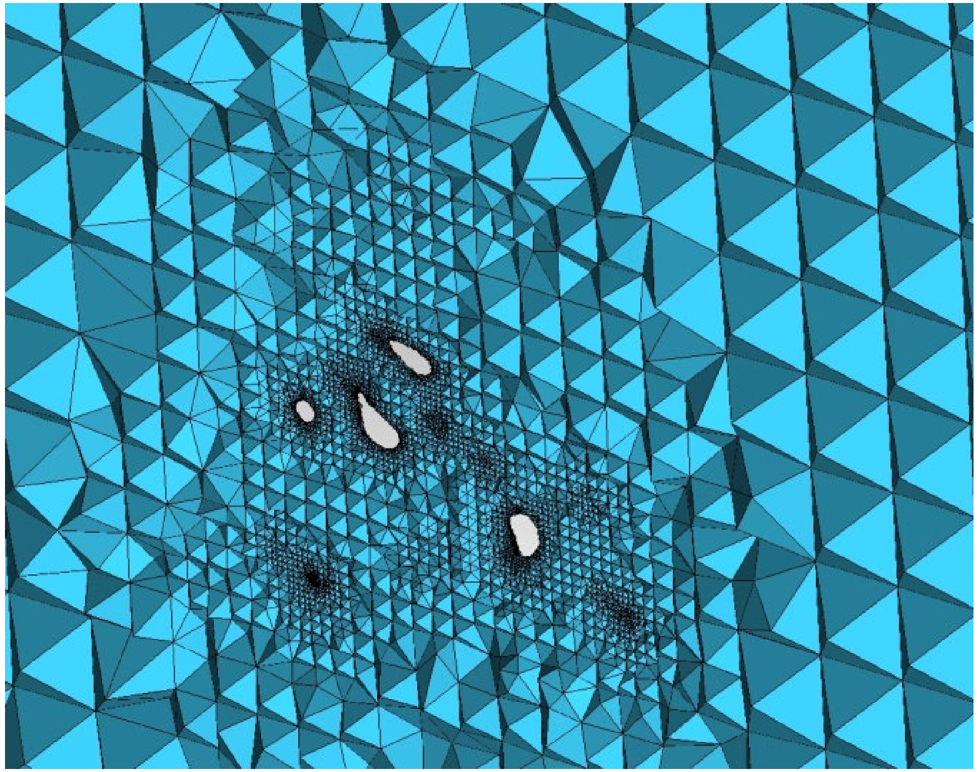
Better description of pores

Conversion of the 3D picture data in the finite element models:
Meshing of the pores and pore-free domains

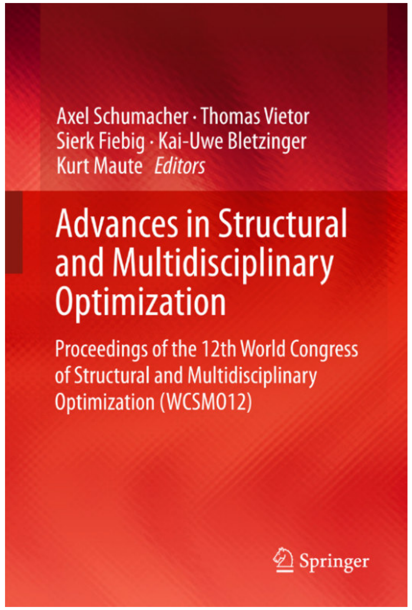




[Schumacher 2012] working group of Prof. Köhnke (Univ. Weimar)

Collection of further activities in the structural optimization community

Multi-objective Reliability-Based Design Optimization for Energy Absorption Components Considering Manufacturing Effects
Huile Zhang, Guangyong Sun, Guangyao Li and Qing Li



Topology Optimization with Integrated Casting Simulation and Parallel Manufacturing Process Improvement
Thilo Franke, Sierk Fiebig, Karsten Paul, Thomas Vietor and Jürgen Sellschopp

A PDE-Based Approach to Constrain the Minimum Overhang Angle in Topology Optimization for Additive Manufacturing
Emiel van de Ven, Can Ayas, Matthijs Langelaar, Robert Maas and Fred van Keulen

Optimal External Support Structure Design in Additive Manufacturing
Yu-Hsin Kuo and Chih-Chun Cheng

[Schumacher 2018b]

Before starting investigations in the integration of the manufacturing process simulation in the optimization loop

Thick about the following questions:

1. How is it possible to quantify the influence of the manufacturing process on the optimal design?
2. Are the simulation models of the manufacturing process good enough for using these in the design loop?
3. How to map the calculated local material behavior on the structural model?
4. Is it possible to use manufacturing simulations in an early stage of the design process?
5. What about the computer time for the simulation of the manufacturing process?

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Conclusion

The following notes are possible:

- There is a strong dependency of the manufacturing process on the structural behavior.
- The examples show the need of the integration of the manufacturing process simulation in the design optimization loop.
- There is a need of efficient methods for the manufacturing process simulation, e.g. one-step-solver.
- Analysis of the effect of using simple manufacturing process simulation tools is necessary.

References (1)

[Dienemann 2016] Dienemann, R., Schumacher, A., Fiebig, S. (2016): “Topology and shape optimization of sheet metals with integrated deep-drawing-simulation”, Proceedings of the 12th World Congress on Computational Mechanics (WCCM XI)

[Dienemann 2017] Dienemann, R., Schumacher, A., Fiebig, S. (2017): “Using topology optimization for finding shell structures manufactured by deep-drawing”, Journal of Structural and Multidisciplinary Optimization (2017) 56:473–485

[Kuenkler 2019] Kuenkler, B. (2019): „Fatigue simulation on car body structures - Current approach and future demands to consider the influence of manufacturing” Proceeding of the Automotive CAE Grand Challenge 2019, 16th and 17th of April 2019 in Hanau, Germany

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[Schumacher 2012] Schumacher, A., Wagner, A., Smarsly, W., Fischer, R., Bartsch, M., Scholz, A. (2012): „Process chain simulation integrated in automatic optimization loops for developing cast parts founded by validated material models”, Proceeding of the 4th European Conference on Materials and Structures in Aerospace, 2012, Hamburg

[Schumacher 2013] Schumacher, A.: Optimierung mechanischer Strukturen. 2. Auflage, Springer-Verlag, Berlin, Heidelberg, 2013

[Schumacher 2018a] Schumacher, A. (2018): "Robust Design through Numerical Analysis - Research State of the Art", Proceeding of the Automotive CAE Grand Challenge 2018, 17th and 18th of April 2018 in Hanau, Germany

[Schumacher 2018b] Schumacher, A., Vietor, T., Fiebig, S., Bletzinger, K.-U., Maute, K. (Hrsg.): Advances in Structural and Multidisciplinary Optimization, Springer Nature, 2018

[Schumacher 2019] Schumacher, A. (2019): „Integration of Manufacturing Process Simulations in the Design Loop” Proceeding of the Automotive CAE Grand Challenge 2019, 16th and 17th of April 2019 in Hanau, Germany

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